Simple quiet tuning and matching of antennas

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Introduction

Quiet tuning is a technique that can eliminate the necessity to radiate a strong carrier while an antenna tuning unit (atu) is being adjusted to match an antenna to a transmitter. In fact the tuning signal can be made so small that it cannot be detected at more than about 1λ from the antenna. Because there actually is a tuning signal the term "quiet tuning" is used, rather than "silent tuning" which would imply correct adjustment of the atu by presetting or by using received noise or signals only.

The technique has in fact been developed by the author and his colleague Peter A. Lewis at the Philips Research Laboratories for use in professional systems [1,2]. However, it is felt that in the simple form described here it should also prove to be of considerable utility to radio amateurs. To illustrate the simplicity of the basic technique, details are given here for adding a quiet tuning facility to the FT101 transceiver or to any transceiver already containing a crystal calibrator. In this case only two extra components are needed, a ferrite bead transformer and a resistor.

Principles of quiet tuning

Normally a reflectometer or standing wave ratio (swr) bridge is used to indicate the correct adjustment of an atu. The atu elements are adjusted until the fraction of the power reflected back into the transmitter is considered to be small enough, or the measured swr is considered to be close enough to 1:1. In a reflectometer or swr bridge there are normally two directional couplers which sense the forward and reflected powers and pass a small fraction of these to rf indicators. These normally consist of a diode detector feeding a fairly sensitive dc milliammeter as shown in Fig 1.

Fig 2 shows how a very large increase in sensitivity can be obtained if the rf indicators are replaced by a receiver tuned to the transmitter frequency which can be switched alternately between the forward and reverse directional couplers. The receiver S-meter can then be used to estimate the swr and to provide a tuning indication. The important point is that the transmitter power can then be reduced by several orders of magnitude and still provide a sufficiently large tuning signal for the receiver to detect. Typically the transmitter power can be reduced well below the microwatt level.

The quiet tune principle is shown in its simplest form in Fig 3. It is based on the observation that the directional couplers in a reflectometer are linear reciprocal devices. This simply means that the position of the transmitter and receiver in Fig 2 can be interchanged without changing the strength of the tuning signal as measured in the receiver. However, this interchange has a very important effect on the signal from the transmitter which passes through the atu and is radiated by the antenna; it is reduced

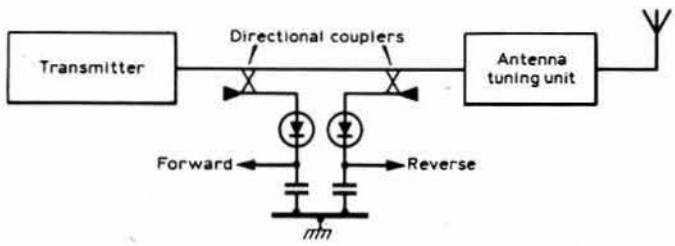

Fig 1. Conventional tuning method

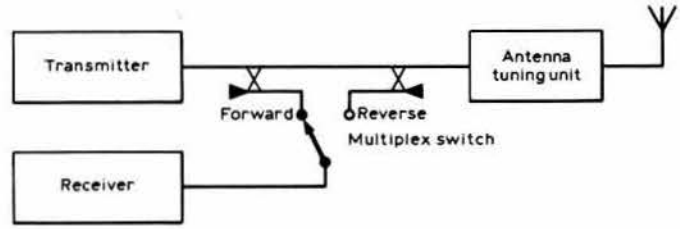

Fig 2. Use of receiver to improve sensitivity and selectivity

in level by the loss through the directional coupler, which typically may be between 20 and 40dB. (Reciprocity also says that the loss is the same for signals passing through a network in the forward direction as for signals passing through the same network or device in the reverse direction.) Under these circumstances the tuning signal need only be about 20dB stronger than any incoming signal on the frequency of interest in order that a 1·2:1 swr or better can be ensured. Such a signal cannot be detected more than about 1λ from a typical antenna [1]; these signals are in the picowatt (10^{-12}) to femtowatt (10^{-15}) range.

With most transmitters it is very difficult to produce a tuning signal which is low enough in level. The easy solution is to replace the very low power transmitter in Fig 3 by a broadband noise source (such as used in antenna bridges for instance). Such a source can cover all frequencies of interest; the receiver will then provide the choice of the tuning frequency and the necessary selectivity. This method has been used by Kit Warren at the Philips Research Laboratories to make quiet tuners which can be placed in the output feeder of any transceiver. In these it is necessary to use directional couplers with enough loss or isolation to protect the noise source from being destroyed by the transmitter power. For transmitter powers up to about 1kW the directional couplers must have a loss between 30 and 40dB so that the noise source must have enough power to overcome these losses.

One solution to this problem can be to use a protection relay to bypass the quiet tuner on transmit. This relay already exists in any transceiver in the shape of the main transmit-receiver antenna changeover relay. This is what is done in the quiet tuner described in the following sections. Another suitable source of tuning signals is the crystal calibrator found in most amateur receivers or transceivers. Clearly the tuning signals then only appear on the discrete calibration frequencies, but there is usually one of these close enough to the desired operating frequency so that any error introduced by not matching on exactly the right frequency is very minimal. Again this is used in the following description.

In operation the quiet tune method is very simple. First the receiver is tuned either on or near the required operating frequency. With the tuning signal source connected to the forward wave directional coupler the receiver S-meter reading is noted. The tuning signal is then switched to the reflected wave directional coupler and the atu adjusted until the original S-meter reading is reduced by at least 20dB (or 3 to 5 S-points). This ensures that an swr of better than 1·2:1 has been achieved on the feeder to the atu.

There is an alternative tuning procedure which eliminates the necessity for the forward wave directional coupler. The reflected wave directional coupler is left permanently connected, then to obtain the initial S-meter reading, a deliberately large mismatch is placed at the atu end of the feeder. This can be done by shorting or grossly mistuning the atu. The mismatch is then removed and the rest of the tuning procedure performed as before.

Directional couplers

The principle of operation of any directional coupler is basically the same. The transmission line voltage and current are sensed and subtracted in proportion to the transmission line impedance. For the forward power, the current and voltage are in phase and hence the resultant of the subtraction is zero. But for any reverse power reflected from an incorrectly adjusted atu, for example, these two components add and give a signal proportional to the amplitude of the reflected wave.

One of the simplest possible directional couplers is shown in Fig 4. Here, for power flowing into input A the total voltage V on the transmission line appears at point B. The current i flowing out of B creates a voltage across the resistor R, and this by transformer action appears stepped up by nine times across the nine-turn secondary winding. This voltage is given by $V_i = 9iR$ and will subtract from the line voltage V to give a voltage V_c at C_i. If a correctly matched 50Ω load is placed on the output B then by Ohm's Law $V = 50i$. From the above the voltage output from C can be calculated as

$$V_c = V - 9iR = 50i - 9iR$$

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If we then make R = 50/9 = 5·6Ω, V_c will be zero for any current i and hence for any power input. For reflected power flowing back into B the subtraction does not occur, so that a voltage proportional to the reflected current will appear at C, which can therefore be used to detect the reflected power only.

At this stage the principle of reciprocity between the "ports" A and C can be invoked and the direction of power flow reversed. This means that provided a 50Ω load is present on port B there will be no power flow from C (the crystal calibrator input) to A (the receiver input). (Those readers who may disbelieve that reciprocity applies in this case can use the usual circuit analysis techniques to confirm this last statement, or try it in practice.)

The directional coupler shown in Fig 4 is not suitable for use with normal transmitter power levels. For example, even with a matched load of 50Ω, 10 per cent of the power put in at port A will be dissipated in the resistor R and only 90 per cent will be passed to the output B. There is therefore a power insertion loss between A and B of 0·9, equivalent to a loss of 0·5dB. When used in the quiet tune system (because of reciprocity) this loss appears in the reciver input, but as far as operation on any hf band is concerned a loss of 0·5dB can be considered to be negligible. With this simple form of directional coupler there are two other facts which might be considered undesirable for other applications, but which are not important here: the receiver connected to port A sees an impedance of 55·6Ω rather than 50Ω, and the crystal calibrator sees an input impedance of 500Ω at port C.

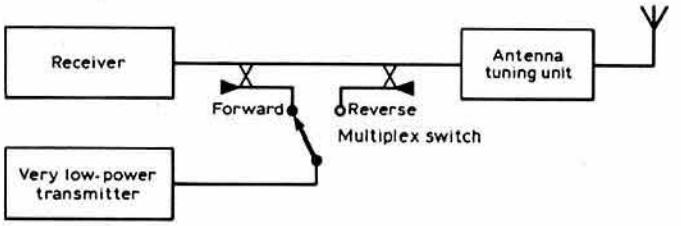

Fig 3. New quiet tuning method

The choice of the ferrite bead for the transformer is not critical, and can be made by the usual rules for good transformer design. However, after a number of trials the Mullard FX2633 8mm ferrite core was found to give the best results over the frequency range 1·8 to 30MHz. With this core in A13 ferrite, only a single-turn primary and a nine-turn secondary are required. With cores of smaller cross-section, 2 and 18 turns were found to be needed, and for larger cores the leakage inductance was found to be too high—causing loss of sensitivity (to the crystal calibrator) at the higher frequencies. (The resistor R should be non-inductive; wirewound types are not suitable.) With tightly-wound windings and the resistor R connected with short leads as close to the core as possible, one may achieve a rejection of the forward power signal by at least 30dB over the 1·8 to 30MHz range. Such an error ensures that the true swr will not be greater than 1·07:1 if the measured swr has been adjusted to exactly 1:1.

One practical point on the use of uncoated ferrite cores such as the FX2633: the edges, particularly the inside edges of the hole, are quite rough and sharp and can strip the varnish or coating of the wire as it is being wound on the core. The use of a small round file on the edges of the hole will remove the danger of shorted turns from this cause.

The simple quiet tuner

The directional coupler shown in Fig 4 is suitable for installing a quiet tuning facility on most receivers or transceivers having a crystal calibrator. Fig 5 shows how it should be connected in a transceiver such as the FT101. The important point is that when on receive the directional coupler should see the feeder to the atu directly. If there is any receiver front-end protection circuitry, as there is in the FT101, this must be left connected between the directional coupler and the receiver input, and not between the directional coupler and the antenna or antenna relay connection.

Installation of the directional coupler is very easy on the FT101. If the primary winding is made of sufficiently stiff wire the core can be supported on it and mounted on the receiver front-end protection board (PB1116). The board is near the antenna changeover relay and is mounted on the side screen of the pa compartment underneath the chassis. The crystal calibrator board lies just outside the pa compartment and very conveniently close to it. A small hole can be drilled in the screen, and the crystal calibrator output (Pin 16 on PB1079A in MJ6) disconnected from its existing connection and rewired through this hole to the directional coupler. The primary winding of the directional coupler is wired in series

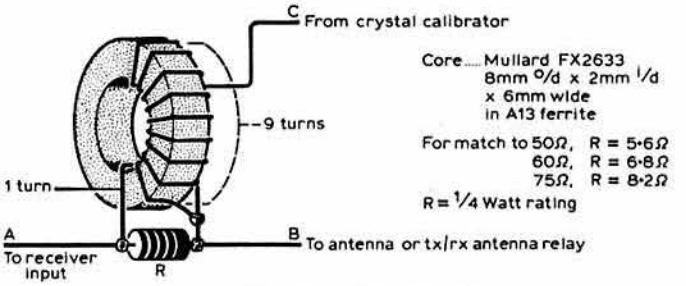

Fig 4. A simple directional coupler

with the existing connection from the receiver protection board to the antenna changeover relay. In the FT101 a 40pF isolating capacitor already exists in series with the output to the crystal calibrator so that the 47pF capacitor shown in Fig 5 is not required. If, as in the author's FT101, there is an extra 220Ω protection resistor R48 wired on the changeover, which appears as a load across the receiver input on receive, this should be removed. If desired the resistor can be rewired to shunt the receiver input on the receiver side of the directional coupler. This completes the modification.

For those who do not like making modifications inside purchased equipment, a quiet tuner can be added externally to the equipment with the use of an extra protection relay. The relay is used to bypass the unit on transmit and, if desired, when the tuning operation has been completed. For the case when the transmitter and receiver are separate there is no problem; the tuner is placed in the feeder to the receiver, and the existing electro-mechanical tr relay provides the necessary protection. Alternatively, to save the extra relay, any directional coupler capable of handling the transmit power can be left in circuit externally and used in reverse. Such directional couplers come in two types; the simpler one being the coupled transmission line type which is frequency sensitive, and the other using a ferrite core current transformer and voltage divider which basically is not frequency sensitive. These are well described in amateur radio literature, such as the *Radio Communication Handbook*, and are used in commercially-available swr bridges. The catch is that, as already mentioned, such couplers have of necessity more loss than the one shown in Fig 4. It is therefore usually necessary to amplify the tuning signal source, whether a broadband noise source or a crystal calibrator. More importantly it is necessary to design the amplifying stage to be capable of withstanding the transmitter power as coupled back through the directional coupler.

For these reasons it is felt that the simple quiet tuner described provides the easiest method of adding the quiet tune facility to most transceivers or receivers.

Results and conclusions

Many tests of the simple manual quiet tuning method have been carried out over the past months by various observers. If anything, the tuning method is easier to use than the conventional high power methods. This may be because, as the tuning signal is nulled by operating the atu, any signals being received are at the same time peaked up, and this subjectively provides confidence that the correct tuning adjustments are being made.

Opinions vary but the general concensus is that a noise tuning signal is not quite so easy to null out as a steady carrier signal, such as obtained from a crystal calibrator. The ideal situation is when the calibrator has harmonics sufficiently closely spaced to the operating frequency to be audible. The atu can then be adjusted while, for example, one is waiting to join a net or to call a new station. This indicates that a calibrator with harmonics spaced by about 2·5kHz would provide the best of both worlds, being easy to null and not requiring the receiver to be retuned after the nulling operation.

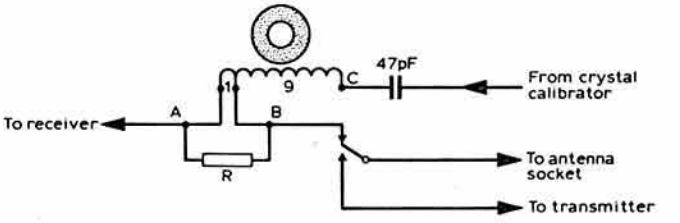

Fig 5. Connection diagram for simple quiet tuner

The quiet tuner on the author's FT101 has been in operation for over a year, and has proved to be entirely successful on all bands 1·8–28MHz. With the load mismatched the crystal calibrator strength as indicated on the S-meter would appear to be slightly stronger on the lower frequency bands 1·8 to 7MHz, but slightly weaker on the 21 and 28MHz bands. On the few occasions when a strong signal has been present on the nearest calibration point, for example on 7MHz, it has always been possible to tune on an adjacent 25kHz calibration point. The technique has proved to be so satisfactory that an swr bridge is no longer used. After quiet tuning the antenna, the transmitter or the linear is tuned and matched to give the maximum output as indicated on the built-in output meter.

In conclusion it is hoped that the more widespread use of the quiet tuning technique will contribute to the reduction of spectrum pollution on the amateur bands as well as improving the operating convenience of amateur stations.

Acknowledgements

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References

[1] "Quiet tuning of antennas", M. J. Underhill and P. A. Lewis, *Electronics Letters* 4 January 1979, Vol 15, No 1 pp37–8.

[2] "Quiet tuning and matching of antennas for radio silence operation", P. A. Lewis and M. J. Underhill, Conference on recent advances in hf communications systems, February 1979. *IEE Colloquium Digest 1979/48.* Also published in October 1980 issue of *IEE Proceedings Part F, Communications Radar and Signal Processing.*

A 70, 144 and 432MHz interference filter for Band 2 fm receivers

by J. F. WILSON, MSc, G3UUT*

THE increasing use of Band 2 fm radios and stereo tuners has, over recent years, led to a rise in interference problems, especially from high-power vhf installations on 70, 144 and 432MHz. On investigation it is often found that the transmitter has a clean output, and the interference is being caused either by spurious responses of the receiver or by blocking, crossmodulation or intermodulation in its rf stages.

Unfortunately in these cases one has no option but to tackle the problem at the receiver. Initially it should be verified that the interference is actually entering the receiver via the antenna lead by unplugging it. If the interference is still present it is probably being caused by direct pick-up on the internal wiring or the mains and speaker leads. In this case, apart from perhaps trying decoupling capacitors across the speaker output terminals, one should seek advice and assistance from the local Post Office radio interference branch as any further work will inevitably require additions or modifications to the inside of the equipment.

Assuming that the interference is entering the equipment via its antenna lead, the next step is to determine the location of the antenna. If an indoor antenna or one inside the receiver is being used, the owner should be encouraged to install an outside antenna. This may cure the problem without further effort, the increased wanted signal effectively desensitizing the receiver to the interference. However, the outside antenna may also pick up more of the interfering signal, and in this case, and where an outside antenna is already in use, one of the following filters may cure the problem.

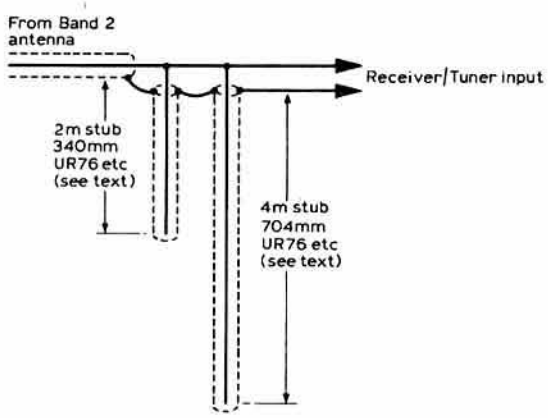

Fig 1. Basic 70, 144 and 432MHz stub filter

Stub filters

A piece of transmission line an electrical quarter-wavelength long at the interference frequency and open circuited at its far end appears as a short-circuit at that frequency. If this is placed in parallel with the antenna input of the receiver, the strength of the unwanted signal may be reduced sufficiently to cure the interference. Open circuit lines also exhibit this property at odd multiples of the frequency at which they are an electrical quarter-wavelength. This is useful because it means that a line (or stub as it is often called) cut to an electrical quarter-wavelength on 144MHz can also be used to remove interference at 432MHz and even 1,296MHz, although the performance at this frequency may not be as good.

Thus, by the use of two pieces of coaxial cable, one cut to an electrical quarter-wavelength at 70·3MHz and the other at 144·5MHz, placed across the antenna input of the receiver, interference caused by 70, 144, 432 and even 1,296MHz transmitters can be removed. The use of two stubs has additional advantages, and it is recommended that even if interference is not present from 70MHz transmissions, or if 70MHz is not used at all, that both the 70MHz and 144MHz stubs are used. The reason for this can be seen by calculating the impedance of each stub at the middle of the fm broadcast band, 94MHz. This shows that the 70MHz stub has an inductive reactance of about 30Ω, and the 144MHz stub has a capacitative reactance of about 31Ω, the two effectively cancelling each other out and forming a low-Q parallel-tuned circuit and ensuring a low loss over the fm broadcast band. The appendix shows the method for working out the lengths of the stubs and the equation for calculating the impedances.

The dimensions of the stubs are shown in Fig 1. This assumes the use of a standard solid polythene insulated coaxial cable, UR57, 67, 76 etc, with a nominal velocity factor of 0·67 (ie the electrical quarter-wavelength of the stub is 0·67 times the calculated value of a quarter-wavelength in air). If a cable with a foam or semi-air-spaced dielectric is used, the velocity factor is likely to be nearer 0·8. However, in this case it is recommended that the stubs are cut too long and trimmed to frequency using a receiver or a dip oscillator. For example, to trim the 144MHz stub, insert it across the antenna terminals of a 144MHz receiver, listen for a strong signal in the bottom half of the band (to ensure that the resonance at 432MHz is not at too high a frequency) and cut short lengths off while watching the S-meter for the minimum reading. To trim using the dip oscillator, set the oscillator to the required frequency (preferably checked on a receiver or

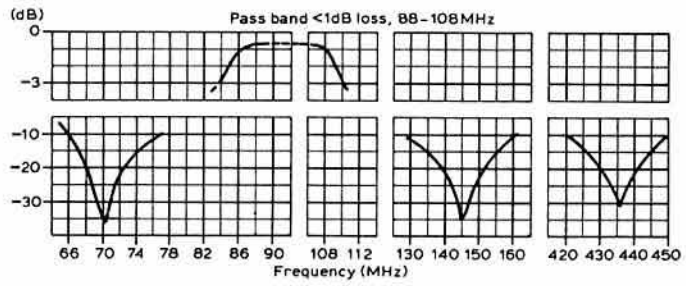

Fig 2. Frequency response of stub filter shown

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